Document Title	**Detailed Specifications of Straight Vacuum Chambers for the HEBT System**
Description	This document describes the detailed specifications of straight vacuum chambers for the HEBT system.
Division/ Organization	VAC/HEBT
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Document History

Version	Prepared/Checked by	Date	Date of Release	Comments
V001	Lukas Urban			Release in EDMS
V002	Lukas Urban			Changes based on the comments from V001
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Detailed Specifications of Straight Vacuum Chambers for the HEBT System

Abstract

This document describes the detailed specifications of straight vacuum chambers for the HEBT system.

Table of Contents

1. Purpose and Classification of the Document

This document describes the detailed technical specifications and production procedures of the straight HEBT Vacuum Chambers for the FAIR accelerator facility. The general requirements related to the common rules and definitions for the FAIR project are specified in the General Specification for the FAIR Accelerator Facility Project [1]. In this document, FAIR GmbH is referred to as the "Company" and the supplier is referred to as the "Contractor". This document only represents the technical part of the contract. No commercial and organisational conditions are considered.

The objective of this document is to provide comprehensive technical requirements for design, production, testing, quality assurance and delivery of vacuum chambers for the HEBT system. It is addressed to all personnel involved in the processes of design, engineering, production, testing and quality assurance.

2. Abbreviations, Terms and Definitions

Abbreviations	Definition
CID no.	Component Identification Number
CDR	Conceptual Design Review
ECR	Engineering Change Request
EDMS	Electronic Document Management System
ESR	Electroslag remelting process
FAIR	Facility for Antiproton and Ion Research
FAT	Factory Acceptance Test
FDR	Final Design Review
FEM	Finite Element Method
HEBT	High Energy Beam Transport
NCR	Non-Conformance Report
PSP	Project Structure Plan
QA	Quality Assurance
QR	Quick Response
RGA	Residual Gas Analyser
SAT	Site Acceptance Test
TG	Technical Guideline

3. Scope of the Technical System

The majority of the vacuum chambers for the HEBT system will be operated at room temperature at an ultimate pressure of less than 10^{-8} mbar. Some of the vacuum chambers will be required to operate at ultimate pressure of less than 10^{-10} mbar and therefore require an *in-situ* bake out cycle.

3.1. Scope of Delivery

A detailed list of all the chambers that have to be delivered can be found in the Overviewlist (Appendix).

The straight vacuum chambers are equipped with two DN160CF and some with DN200CF flanges. Some chambers require a fixed bellow either on one side or on both sides of the chamber. In addition, each vacuum chamber must include all necessary components required to fix it to the stand, such as any kind of supports, screws, nuts and bolts.

Each vacuum chamber is assigned by:

- Work package breakdown structure element (PSP code)
- Drawing number for vacuum chamber
- CID number – component identification number that is unique for each chamber

4. Procedures

4.1. Overall Procedures

Within an agreed period after signing the contract, the Contractor must present a project schedule which indicates the following phases and milestones:

- Design Phase (involving CDR and FDR),
- Series Production,
  - Factory Acceptance Test (FAT) of the series of production
  - Site Acceptance Test (SAT) of the series of production
- Delivery (Packing and Transport).

Section 4.2.1, Section 4.2.2, Section 4.2.3 and Section 4.2.4 describe each of the milestone steps in detail.

While the project is in progress, the Contractor must provide a monthly report describing the completed tasks of the previous month and the tasks to be done in the following month. The completed tasks should correspond with the project schedule. Any deviation from the agreed project schedule has to be explained in the report. The progress of the project and the monthly report will be discussed in the monthly meeting, with the presence of the Company and the Contractor.

Furthermore, the Contractor must fill in the “Progress Report Spreadsheet” provided by the Company. This spreadsheet contains a matrix of the current status of all necessary elements required for each vacuum chamber: delivery, material procurement, flanges, mechanical measurement for production, additional components (supports, mounting brackets, etc.), chamber cleaning, vacuum tests, delivery, etc. The Company will evaluate this progress report every month.

4.2. Design Phase

4.2.1 Technical Drawings

The Company will deliver a draft design (both 3D models and 2D drawings) of the vacuum chambers. The 3D models and 2D drawings are given with the nominal aperture. Based on this draft design, the Contractor has to prepare his own model and technical drawings (3D models and 2D drawings) for the 'series production' of the chambers. The technical drawings created by the Contractor must comprise all technical details required for the chamber manufacturing, such as: tolerances, welding specifications, cleaning procedure and vacuum firing. The technical drawings must conform to FAIR Technical Guideline F-TG-MDS-en-KRL and Data Exchange Guidelines I and II (F-TG-B-02e and F-TG-B-03e). The design of the vacuum chamber has to follow relevant FAIR Technical Guidelines.

A "skeleton" can be found in the 3D models and 2D drawings provided by the Company. The skeleton is a simplified representation of the beam path in the vacuum chamber. This must be taken into account in the design of the vacuum chambers and must be integrated into the 3D models provided by the Contractor. The skeleton comes first in the tree structure of the 3D models and it could be made out of lines and points, but can also be executed as a 3D body due to technical issues.

4.2.2 Supporting Documents

In addition, the Contractor has to provide the following:

- A mechanical stability analysis, i.e. a stress analysis by using, for example, FEM simulations. The mechanical stability analysis must be done for each type of chamber with different dimension in the cross sections and length,
- Production/manufacturing process plan
- Inspection and test procedures
- Q – Plan (as specified in Section 7)
- Risk assessment
- Operation Manual

4.2.3 Conceptual Design Review (CDR)

In the CDR, the Company will review the 3D models and supporting documents (as listed above, at draft level) prepared by the Contractor. All necessary documents for the review must be prepared and sent to the Company **14** working days before the review. Once the Company approves the 3D models and all other supporting documents, the Contractor can start creating the 2D drawings. More details about the CDR can be found in F-VA-QUA-en-0006_Design_Reviews-V006.

4.2.4. Final Design Review (FDR)

The Company releases the 2D drawings during the FDR. In the FDR, the Contractor has also to provide all the supporting documents (as listed above, at final level). All necessary documents for the review shall be prepared and sent to the Company **14** working days before the review. After the FDR release, the Contractor can then take further steps, i.e. manufacturing the first of series chamber and/or series production.
If there is any change in the 3D models or 2D drawings after the release of FDR, the Contractor has to suggest the amendment to the Company. The Company has to agree on this amendment before the production can start. More details about the FDR can be found in F-VA-QUA-en-0006_Design_Reviews-V006.
Any deviation during the production from the released design or from the agreed schedule has to be reported to the Company. A Non-Conformance Report (NCR) has to be created by the Contractor for any deviations occurring during or after production. The NCR has to be approved by the Company first, before the production may be continued.

5. Technical Specifications

5.1. Vacuum Chambers

Vacuum Chamber and Flange Materials

The material for the vacuum chambers and CF-flanges on the knife-edge has to follow the DIN EN 10088. The material for the vacuum chamber has to be stainless steel of type 1.4304, 1.4306, 1.4307, 1.4429, 1.4435 or higher quality and must be free of pores and inclusions.

The material for the CF-flanges has to be stainless steel 1.4301 or higher quality and must be free of pores and inclusions.

The material for the bakeable CF-flanges has to be stainless steel 1.4429 ESR and must be free of pores and inclusions (ISO 3669).

Bellows

The dimensions and requirements for bellows can be found in the draft version of the 2D drawings that will be delivered by the Company.

Chamber Wall Thickness

The chamber wall thickness given in the draft 3D models/2D drawings is not a fixed parameter. The Contractor may propose a different wall thickness within the tolerance and without altering the other dimensions, such as the nominal aperture. In addition, the mechanical stability of the chamber has to be verified (by FEM analysis, for instance).

5.2. Vacuum Properties

The RGA spectra must be recorded **continuously** in the range 0 ... 100 a.m.u. without changing any parameters during the recording, i.e. a partitioning of the measurement range and recording with different RGA parameters is **not** allowed. In order to be able to distinguish true measurement readings from (electronic) noise, the RGA spectra must be recorded in analog scan mode, i.e. a bar graph representation of the measurement data is not allowed. Furthermore, it must be evidently visible that the signal-to-noise ratio is acceptable, i.e. RGA spectra dominated by (electronic) noise cannot be accepted.

The following vacuum properties have to be fulfilled by the vacuum chambers:

(a) For non-bakeable chambers:

Integral leak rate < 1 x 10^{-10} mbar l/s

Outgassing rate < 5 x 10^{-10} mbar l/s cm^2, after 10 hours continuous pumping

Residual gas composition – after 24 hours continuous pumping:

- Dominant mass peak must be water H_2O (18 a.m.u.)
- All peaks from masses between 18 and 45 have to be 100 times lower than the peak from mass 18, except peaks from masses 28 and 44
- All peaks from masses higher than 45 have to be 1000 times lower than the peak from mass 18

(b) For bakeable chambers:

Integral leak rate < 1 x 10^{-10} mbar l/s

Outgassing rate < 1 x 10^{-12} mbar l/s cm^2, after 24 hours continuous pumping with

Bake out at max. 300 °C

Residual gas composition: - after 24 hours continuous pumping and cooling to room temperature after the bake out cycle:

- Dominant mass peak must be hydrogen H_2 (2 a.m.u.)
- All peaks from masses 12 up to 18 and the peak mass 28 have to be ≤ 10% of the H_2 peak
- All the peaks from masses 22 to 32 (except peak 28) have to be ≤ 0.5% of the H_2 peak
- All the peaks from masses 34 to 48 (except peak mass 44) have to be ≤ 0.25% of the H_2 peak
- The peak from mass 44 has to be ≤ 5% of the H_2 peak
- All the peaks from masses 49 to 100 have to be ≤ 0.1% of the H_2 peak

5.3. Mechanical Stability

The Contractor must provide a proof of the mechanical stability of the vacuum chamber under operating condition. The chamber must withstand sudden pressure changes without any lasting deformation. It is recommended that the analysis for this mechanical stability is performed using FEM analysis (FAIR Technical Guideline F-TG-K-10.14e). The analysis results concerning the mechanical stability have to be presented in a report, which will be used as part of a design review by the Company.

5.4. Surface Properties

The vacuum surfaces must be smooth, free from scratches, and show no contamination, no holes, no traces of corrosion or oxidation, and no colouring effect from annealing, welding or any other manufacturing processes. Any surface defects have to be removed only via methods that are accepted by the Company. Scraping or wheel grinding and stainless steel brush are allowed but without the use of any grease, oil, or other grease products. Any plastic materials, especially PVC, are not allowed in contact with the vacuum surfaces.

The vacuum side surface roughness has to be R_z<25.

6. Manufacturing

6.1. Welding

- Welding seams have to be done from the vacuum side only. Deviations from these requirements are only allowed with the agreement of the Company in written form. Welding seams which are done from the outside, have to be welded completely through that no voids can occur (full penetration welding).
- Welding seams between tubes and flanges have to be done without any additional material. Exception: If the flange has to hold a weight of 70kg or more, suitable filler material is allowed. Flanges shall be welded after complete machining. It is not allowed to rework the chamber after welding. No deformation of the flanges is allowed due to welding.
- Welding seams for stabilisation or tack welds, which cover the vacuum tight welds, have to have interruptions to allow helium flow during leak tests.
- Porosity, cracks, inclusions, cold shuts, undercut or under fills of the welding seams are not allowed. Any brushing or other work on the finished welding is not allowed, except the use of stainless steel brush.
- All welding seams have to be done by a certified welder. More information about vacuum welding seams can be found in the FAIR technical guideline F-TG-V-3.1e.
- All welding seams have to be checked by a certified inspector (following DIN EN ISO 9712 — Qualification and Certification of Non-Destructive Testing Personnel). The welding seams have to fulfil DIN EN ISO 5817 quality class B.

6.2. Flanges

Most chambers have to be equipped with fixed flanges and must be able to hold a weight of minimum 70kg in vertical and 200kg in horizontal direction. Some of the chambers, however, require rotatable flanges. The type of flanges will be indicated in the drawings provided by the Company.

6.3. Cleanliness during Manufacturing

- It is essential to keep the rules of UHV practice throughout the manufacturing of vacuum components.
- All tools, equipment and machines used to manufacture the vacuum components have to show the necessary cleanliness.
- The cleanliness of the surfaces facing vacuum during the entire manufacturing process is crucial. The vacuum surfaces must not display any traces of corrosion, oxidation, or annealing colours. Details of the cleaning procedure will be clarified in the contract. An example of ultrasonic cleaning can be found in the guidelines F-TG-V-6.1e and F-TG-V-6.3e.

6.4. Labelling

All vacuum chambers have to be marked with the CID number and the finalised drawing number of the chamber provided by the Contractor and the material of the flange. These labels shall be permanently etched or engraved on the outer surface of the flange. In addition, all chambers have to be labelled with a metal tag containing a QR code. The CID number and the QR code will be designed and supplied by the Company. The details of labelling procedures can be found in the Technical Guideline F-TG-B-05e.

7. Quality Assurance (QA)

7.1. Quality Assurance System of the Contractor

It is recommended that the Contractor is certified according to DIN EN ISO9001 or has implemented a quality management system fulfilling comparable requirements. The Contractor shall provide a Q – plan according to [1]. The Q – plan shall include the quality management plan, manufacturing and production processes, quality control, testing and inspection procedures, and certificates. Each equipment, instrument or tool required for testing and inspection has to be calibrated (proven by its calibration certificate stating its measurement uncertainty) and shall be capable for its task. Material certificates according to DIN EN 10204 3.1 have to be provided for all material used to build the chamber. In addition, a skilled person carrying out some processes (e.g. welding) needs to have valid certificates (e.g. according to DIN EN ISO 9606-1).

7.2. Factory Acceptance Test (FAT)

The FAT is a mandatory step for each chamber. The FAT for the pre-series chambers will be carried out at the Contractor's site, with the presence of the Company. For the series production chambers, the FAT may be carried out by the Contractor without the presence of the Company, if agreed by both parties. The Contractor has to provide all the necessary tools, equipment setup, and facilities for the FAT procedures.

The FAT of any chamber must include the following test:

- Visual Inspection
  - The Contractor has to examine the internal and external surfaces of the vacuum chamber for any defect, scratch, dirt, contamination, dent and any form of colour that may originate from the welding or annealing.
  - All welded parts must not have any scale, void, or blow holes and there is no visible evidence for inclusions or any colour from the welding. The welding seams have to follow DIN EN ISO 5817 quality class B.
  - The sealing flanges and the knife edges must be clean and free from any defect
  - The inspection of the internal parts has to be done with special care, in order not to cause any contamination or scratches inside the chamber.
- Mechanical Inspection
  - The Contractor has to guarantee that the dimensions of the vacuum chamber are according to the drawings.
  - The mechanical measurement of some dimensions of the vacuum chamber has to be verified by a 3D measuring machine. The chamber parts that need to be measured by the measuring machine will be determined in due course.
  - The number of flanges, additional mounted parts to the chamber, and the use of standard components have to follow the approved design.
- Vacuum Acceptance

  The Contractor must provide the information of the leak rate, outgassing rate, and the residual gas composition during the vacuum acceptance test (see Section 5.2). Detail of the vacuum acceptance test is specified in the FAIR Technical Guidelines F-TG-V-7.2e.

All the test results must be summarised in an inspection report for FAT. The CID of the vacuum chamber must be included on the cover page and also on the header of each page in the FAT Inspection Report.

If the FAT fails, the Contractor is responsible to carry out all necessary repair work. A repair work can only be carried out with the permission from the Company. If the repair or rework is not feasible, the Contractor has to reproduce the chamber with all necessary arrangement that has to be approved by the Company, such as revised schedule, re-design, or modifications in the manufacturing process.

7.3. Site Acceptance Test (SAT)

A SAT will be conducted for each first-of-series chamber, carried out after a completed and successful FAT and approval of delivery by the Company. SATs of chambers from the series production may be carried out at random by the Company.

The SAT will be carried out at the Company's site. In general, the SAT will involve visual inspection, mechanical acceptance test, vacuum acceptance test, and other necessary tests (e.g. x-ray test of the welding). The Company reserves the right to do additional tests, especially if there is any doubt about the quality of the chamber.

If the SAT fails, the Contractor is responsible to conduct any necessary repair or rework. If the vacuum chamber must be returned to the Contractor, the FAT process has to be repeated.

If the repair or rework is not feasible, the Contractor has to reproduce the chamber with all necessary arrangement that has to be approved by the Company, such as revised schedule, re-design, or modifications in the manufacturing process.

8. Packing and Transport

8.1. Final Packing

After the vacuum chamber has passed the FAT, the chamber has to be filled with dry nitrogen (recommended purity of 99.995%) and sealed with clean aluminium covers (see F-TG-V-9.12e). The seal can be implemented using either the same type of blind flanges such as the counter flange or sealing covers of aluminium with a pinch-off edge. The sealing of the chamber and recipient need not to be a vacuum seal; since it shall only prevent air from flowing into the chamber, which is filled with nitrogen.

The packaging shall be executed in such a way that it retains the shape of the components and that the vacuum surfaces do not become scratched.

8.2. Transport

After the final packaging, the chambers have to be stored in a clean environment. It should be ensured that the chambers remain clean and ready for the installation. The transports of the chambers has to be conducted in such a way that it retains the shape, conditions, and cleanliness of the chambers. It is recommended that the chambers are wrapped in a weather tight packaging and secured in a wooden box for transport, to avoid any damage or scratches on the surface due to friction and collision.

Detail of packing and transport of vacuum components can be seen in the FAIR Technical Guideline F-TG-T-0.1e-V002.

9. Documentation

All documentation, either in electronic or paper form, which has been used for the design, construction, manufacturing, inspection and testing of the vacuum chamber, will become property of the Company. All documentation, involving drawings, procedures, protocols, reports, certificates, and all important communication will be uploaded into EDMS by the Company. The Contractor also has to upload all the updated drawings and reports into the EDMS. The process of uploading the documents will be explained in due course. All documents must be written in English. Only the operating manual must be written in German.

10. References

[1] F-GS-PMO-en-General_Specification: General Specification for the FAIR Accelerator Facility Project.

11. Related Documents

11.1. Technical Guidelines

F-TG-MDS-en-KRL	Design Guideline
F-TG-B-02e	Data Exchange Guideline I
F-TG-B-03e	Data Exchange Guideline II
F-TG-V-2.6e	Material for bakeable CF-Flanges
F-TG-V-3.1e	Constructive Design of Welding Seams for Vacuum Chambers
F-TG-V-7.2e	Vacuum Properties Acceptance Test without Bake-out
F-TG-VAC-en-V_7_3_e	Vacuum Properties Acceptance Test with Bake-out
F-TG-V-9.12e	Sealing Cap CF Flanges
F-TG-T-0.1e	Transport
F-TG-V-6.1e	Cleaning of UHV Components of Stainless Steel
F-TG-V-6.3e	Cleaning of Bellows Used in Beam Vacuum
F-TG-B-05e	Permanent Tagging and Labelling of Components
F-TG-K-10.14e	FEM Analysis

11.2. Procedural Instruction

F-VA-QUA-en-0006	Design Reviews

12. Appendix

12.1. Overviewliste_AP4_straight tubes

12.2. Drawings_AP4_straight_tubes